STATUS REPORT

TO

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOR

NsG 708

A GRANT IN SUPPORT

of

BASIC RESEARCH IN SEMICONDUCTOR DETECTOR-DOSIMETER CHARACTERISTICS, AS APPLIED TO THE PROBLEMS OF WHOLE BODY DOSIMETRY

From

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I Abstract

For protons up to 187 Mev, the charge pulse created in a silicon semiconductor detector has been shown to be directly proportional to the energy absorbed in the sensitive volume--whether the ionizing particle is totally absorbed or not--and to be independent of the specific ionization of the ionizing radiation producing the response. Research has shown that properly designed detectors can be used to measure the total energy absorbed in a known volume of silicon, i.e. the "silicon dose", under heterogeneous radiation field conditions and also to obtain the linear energy transfer (LET) spectrum. It is proposed here to continue basic research on the characteristics of silicon and other semiconductor detectors to determine the proper design and construction as well as the limitations for detectors used as dosimeters. Calibration techniques, as well as techniques for verification of measured value as true energy absorbed, will be given major attention.

Experimental and theoretical translation of "silicon dose" into "tissue (muscle, fat and bone) dose" is to be accomplished for protons over the proposed range of energies found in solar flares and in the Van Allen belts. Both atomic and nuclear interactions between the incident protons with a) silicon and b) the atoms pertinent to muscle, fat and/or bone composition will be studied theoretically and experimentally.

II Technical Description

A. Statement of the Problem:

Energy is imparted to matter by excitation and ionization (E_{ion}) or by nuclear interaction (E_{nuc}). These processes create secondaries which in many cases have energies (E_{es}) great enough to escape a small volume, e.g., a small dosimeter, chosen for a dose determination. If any increase in rest mass takes place in nuclear or elementary particle reactions within the chosen volume, this quantity of energy, E_{rm}, must be considered. The energy absorbed in a given volume may be expressed by

$$E_{abs} = E_{ion} + E_{nuc} - E_{es} - E_{rm}.$$

The biological effect of radiation depends upon (1) the ion density along the track of an ionizing particle, (2) the ion density surrounding the site of a nuclear interaction, and (3) the total energy absorbed. The same dose, i.e., total energy absorbed from ionizing radiations of different LET values can produce quantitatively and qualitatively different biological effects. Any physical measurement of dose should provide information concerning both energy absorbed and the LET spectrum at the site of interest.

It has been shown that, for protons having energies up to 187 Mev the charge pulse created in a silicon semiconductor detector is directly proportional to the energy absorbed in the sensitive volume. Thus semiconductor detectors, properly used, have the capability of measuring both the energy absorbed in the sensitive volume of the detector and the silicon LET spectrum during exposure to ionizing radiation. Silicon dose and silicon LET spectrum must then be translated into tissue (muscle, fat and/or bone) dose and LET spectrum for meaningful biological dosimetry.

The research conducted under this grant will have as its objectives:

1. to study the basic characteristics of semiconductor detectors, in order to determine the physical characteristics which a detector-dosimeter must have to make physical measurements of energy absorbed in a known mass, and the corresponding LET spectrum for protons over the range of proton energies found in the Van Allen belts and in solar flares; and

2. to determine both theoretically and experimentally the proper translation of energy absorbed in the sensitive volume of the detector-dosimeter into dose and LET spectrum for muscle, fat and bone as a function of proton energy.

B. Progress Report: June 1964-January 1966

I. Experimental Progress

A. Lithium Drifted Silicon Semiconductor Detectors:
1. Fifty-four different detectors have been incorporated into this study. They represent a family of various sized devices ranging in size from 1 x 1 x 1 mm to 7 x 7 x 150 mm. Long detectors, i.e., having proton path lengths in silicon of 10, 20, 30, 50, 70, 100, 120, 130 and 150 mm are being used to totally absorb high energy protons. Shorter path lengths are used to measure stopping power $dE/\rho dX$ in silicon.
2. Southern Methodist University has the capability of fabricating Lithium-drifted detectors of any desired shape. New techniques of fabrication, mounting and encapsulation are being developed.
3. Combinations of detectors have been developed to permit simultaneous measurements of dE/dx and E with positive identification of both the mass and energy of the incident particle for translation to a surface dose and depth distribution.

B. Stopping Power Measurements:

Data has been taken using protons having energies of 5, 6, 8, 10, 11, 12, 13, 14, 15, 16, 36, 37, 40, 100, 160, and 187 Mev. Absorbers were used in duplicate sets of three different thicknesses permitting measurements on six different absorbers with each of two or more detectors.
   a. Elements: Al, Cu, Si, C.
   b. Plastics: Nylon, plexiglass, polyethylene, tissue equivalent.
   c. Tissue: Bone, muscle, fat.

C. Charge-pulse response of silicon detectors:

The charge-pulse response of many of the detectors have been measured for the proton energies listed in B. as a function of proton energy, proton path length in silicon and operating conditions of the detector. The average energy required to produce an ion-electron pair has been obtained from both the stopping power measurements in silicon and from the protons totally absorbed in silicon. These data are required to translate the current from each detector produced by a known radiation flux density and stored in a calibrated condenser into dose, i.e., the total energy absorbed per unit mass of silicon.

D. Detector Life-time Behavior Studies:

The depletion depth, volume, noise level, charge pulse per Mev, dark current and capacitance are being measured for each detector used in the study. The complete age-usage history thus obtained over the two year period will be used to a)predict the usable life of a detector and b) to pin-point and predict loss of reliability of data produced by the detector.

E. Field Trips:

1. to the University of Texas, Austin, Texas
   Dates: October 10-11, 1964
   Accelerator time: 36 hours
   Proton Energies 5-14 Mev

   Dates: December 28-29, 1964
   Accelerator time: 36 hours
   Proton Energies 8-16 Mev

2. Oak Ridge National Laboratories, Oak Ridge, Tennessee
   Dates: November 21-29, 1964
   Accelerator time: 80 hours
   Proton Energies: 36-40 Mev

3. University of Uppsala, Uppsala, Sweden
   Dates: October 23-November 8, 1964
   Accelerator time: 100 hours
   Proton Energy: 187 Mev

4. University of Southern California, Los Angeles, California
   Dates: May 20-22, 1965
   Accelerator time: 24 hours
   Proton Energies: 21-30 Mev

5. McGill University, Montreal, Canada
   Dates: August 4-15, 1965
   Accelerator time: 110 hours
   Proton Energy: 100 Mev

6. Harvard University, Cambridge, Mass.
   Dates: August 16-19, 1965 NOTE: Cyclotron main generator failed just before SMU turn to "go on the beam." This major breakdown forced rescheduling field trip to
   Dates: January 18-24, 1966
   Accelerator time: 84 hours
   Proton Energy: 160 Mev

F. NASA Participation:

Members of the NASA, Manned Space Center, Space Radiation and Fields Branch participated in the research effort at the University of Uppsala, at Oak Ridge National Laboratory, and at McGill University. At each facility additional research of special interest to this Branch were accomplished. These included exposure of nuclear track plate emulsions and calibration of various dosimeters. The accelerator time made available to NASA at no charge ranged from 10 to 24 hours at each facility.

II. Theoretical Progress

A. Linear Stopping Power Calculations:

A program for calculating linear stopping power, $dE/\rho dx$; based on the Bethe-Block equation

$$- \frac{dE}{\rho dx} = \frac{e^2 \, 4\pi \, mc^2 r_o{}^2 N_o}{\beta^2} \frac{Z}{A} \left[\ell n \; \frac{2 \, mc^2 \beta^2}{1 - \beta^2} - \beta^2 - \ell n \, I - \frac{\Sigma Ci}{Z} \right]$$

including shell corrections has been completed, tested and used on the SMU, CDC-1604 computer to calculate the correct thicknesses for the pure absorbers, Al, Cu, Si, and C. The mean ionization potential, I, has been evaluated experimentally for each element.

B. Monte Carlo Stopping Power Calculations:

The linear stopping power program has been incorporated into a Monte Carlo transport program which permits Coulomb interaction with both the orbital electrons and the nuclei. This program has been used to verify the stopping power measurement and the energy straggle measured experimentally.

C. Determination of Z, A and I for complex absorbers:

The above programs are being used to determine effective Z, A, and I values for water, bone, meat and fat based on the experimental stopping power measurements. The end result will be a program by which dose, i.e., the total energy absorbed per unit mass of the absorbing material, can be calculated as a function of flux density, type and energy of the ionizing radiation.

D. Calculation of Effective Z, A, and I.:

The effective values of Z, A, and I for each of four plastics studied are being used to obtain a mathematical model for calculating these quantities where the chemical composition and relative abundance of a heterogeneous material is known.